Microstructures of Planetary Nebulae with Large Telescopes

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Abstract. Planetary nebulae (PNe) are known to possess a variety of small-scale structures that are usually in a lower ionization state than the main body of the nebulae. The morphological and kinematic properties of these low-ionization structures (LISs) vary from type to type in the sense that LISs can appear in the form of pairs of knots, filaments, jets, and isolated features moving with velocities that either do not differ substantially from that of the ambient nebula, or instead move supersonically through the environment. The high-velocity jets and pairs of knots, also known as FLIERs, are likely to be shock-excited. So far, most of the FLIERs analyzed with ground-based small and medium telescopes, as well as with the HST, do not show the expected shock-excited features —either the bow-shock geometry or the shock excited emission lines. In this talk we discuss the crucial problem of the excitation mechanisms of FLIERs —through the comparison of jets and knots of NGC 7009 and K 4-47— and what might be the contribution of large telescopes.

MACRO- AND MICROSTRUCTURES OF PNE

The main, macro, structures of PNe are the elliptical, bipolar, or point-symmetric rims and shells, as well the haloes that dominate the optical [O III] and Hα line emission of planetary nebulae (see top panel of Figure 1). Notwithstanding important revisions, the mechanism responsable for the rim formation has been known for almost 30 years as the interacting stellar wind, ISW, models (Kwok, Purton & FitzGerald 1978). Now we believe that, in addition to the interplay between the slow AGB and the fast post-AGB winds, magnetic fields and rotation —probably due to a disk within a binary system— should also play a role in the formation of the main structures of the PNe (for a review, see Balick & Frank 2002). The formation of the shells, external to the rims, has been ascribed to the action of the photoionization front on the AGB matter not yet reached by the shock produced by the fast wind (e.g., Schönberner 2002). The outer halo in its turn is interpreted by Corradi et al. (2003) as being composed by matter ejected during the AGB phase, its outer edge marking the signature of the last AGB thermal pulse.

The microstructures of PNe, on the other hand, are far less understood theoretically. That they are much more prominent in the lower ionization optical emission lines ([N II], [S II], [O II]), appear on smaller scales than the main structures, and are usually different of the main bodies in terms of morphology and kinematics, gives us some guidelines in attempting to unveil their origin. A number of papers have recently been published on the subject, in which some aspects of their origin are treated. From observations, we know that: LISs appear as pairs of jets, knots, filaments, and jetlike features, or as isolated systems (bottom panel of Figure 1); LISs sometimes expand with the rim, shells, or

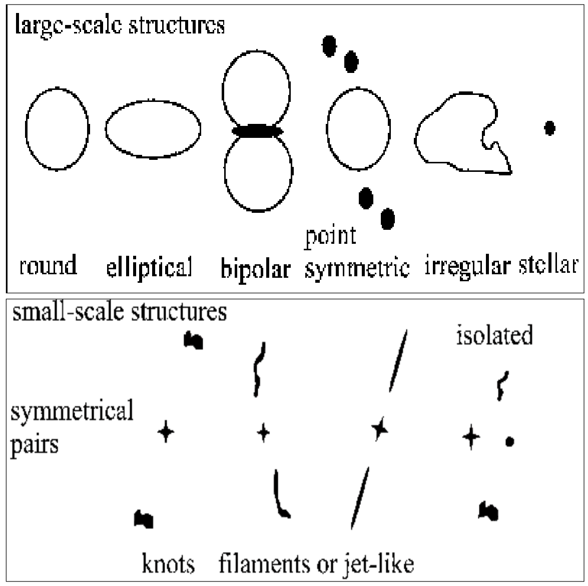

FIGURE 1. Morphological classes of PNe. Top: The main components. Bottom: The microstructures, LISs.

haloes in which they are embedded, but sometimes they are much faster than the main PNe components; they are spread indistinctly within all the morphological classes of PNe; in general, they do not have an important density contrast with respect to the main bodies; and most LIS systems studied up to now are mainly photoionized.

With regard to the comparison of LIS properties with theoretical predictions, some of their characteristics seem hard to explain (see Balick & Dwarkadas 1998; Gonçalves et al. 2001, 2003; Balick & Frank 2002). However, the origin of part of these systems (from their morphology and kinematics) can be reasonably understood via ISW models, in single stars or binaries, with or without magnetic fields, precession, and wobbling.

LOOKING FOR SHOCK EXCITATION IN LIS

Because the high-velocity pairs of knots and jets are highly supersonic, it is expected that their optical emission line spectrum show line ratios characteristic of shock-excited emission.

Figure 2 and 3 show three diagnostic diagrams for K 4-47 and NGC 7009, in which the excitation of the different regions of these PNe can be checked. From the figures, the high-velocity pair (Knot1–Knot2) of LISs in K 4-47 is mainly shock-excited, while its core is locate out of the shock regime zone, much closer to the loci of the photoionized structures. In contrast, NGC 7009 has three pairs of highly supersonic LISs —the knots K1–K4, K2–K3, and the jets J1–J2— in addition to its rim (R1–R2). In this case, none of the features, either LIS or rim, fits the zone of the shock-excited emission.

As in K 4-47, a few other PNe were found with shock-excited features: M 1-16 (Schwarz 1992, Huggins et al. 2000); and M 2-48 (López-Martín et al. 2002). What

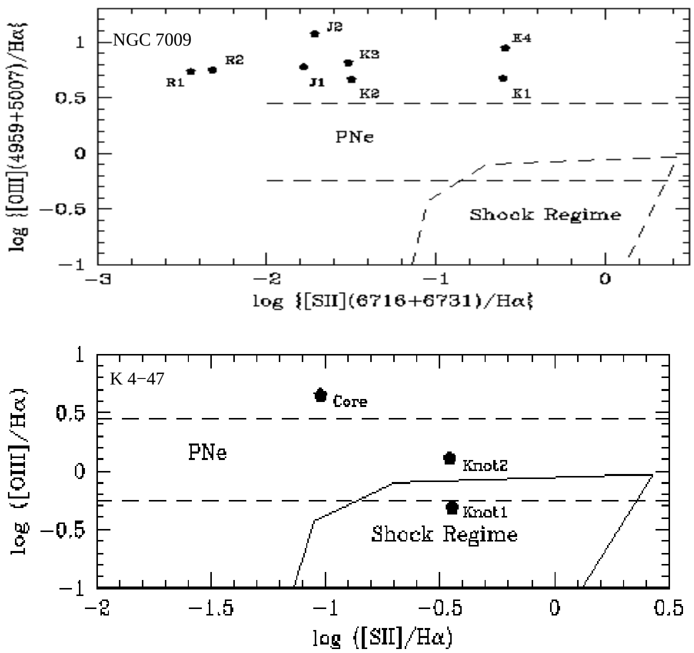

FIGURE 2. The [O III]/Hα *vs.* [S II]/Hα diagram showing the excitation of the eight regions of NGC 7009 (top) and three of K 4-47 (bottom), from 2.5 m INT long-slit medium-resolution spectra (see Gonçalves et al. 2003, 2004).

these three PNe have in common is that they are highly collimated bipolar PNe; have high-velocity structures (100 up to 300 $\mathrm{km\,s^{-1}}$); and share properties with young PNe. NGC 7009, on the other hand, seems to be more evolved than K 4-47, M 1-16, and M 2-4.

WHAT ABOUT “THE LARGEST TELESCOPES”?

The fact that the expected shock excitation of jets and other high-velocity LISs is not usually observed —in evolved PNe— could mean that jets/knots are relaxed systems in the sense that shock excitation is no longer present because LISs were already reached by the energetic photons of the post-AGB central star, and/or affected by local instabilities (Dopita 1997; Miranda et al. 2000; Soker & Reveg 1998). This seems to be the case for NGC 7009. In fact the PN NGC 7662 was observed with the HST (WFPC2 and STIS) and no shock-excited emission was found to be associated with its FLIERS (Perinotto et al. 2004). Therefore, it is clear that either shocks are not present in evolved PNe (not even associated with the highly supersonic LISs) or the ‘the thickness of the shocked layer in LIS is too small to be resolved with HST,’ as suggested by the latter authors.

Two ways of further investigating this issue are therefore: i) to determine via simulations the size of the shock zone (or the thickness of the working surface associated with the shock) of LISs in evolved PNe, and ii) observe these structures with the largest telescopes, which would give a spatial resolution better than with the HST.

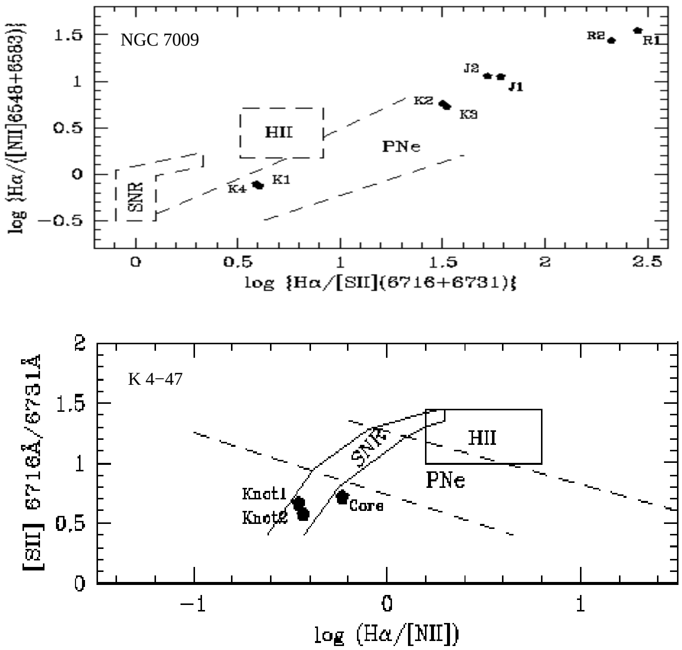

FIGURE 3. As in Fig. 2, but in the Hα/[N II] *vs.* Hα/[S II] and [S II](6716Å)/[S II](6731Å) *vs.* Hα/[N II] diagrams.

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